Survey of Red Sea Urchin Populations In Fitz Hugh Sound, British Columbia, 2001

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SURVEY OF RED SEA URCHIN POPULATIONS IN FITZ HUGH SOUND, BRITISH COLUMBIA, 2001

by

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ABSTRACT

Atkins, M., Tzotzos, D., Campbell, A., and Hajas, W.C. 2006. Survey of red sea urchin populations in Fitz Hugh Sound, British Columbia, 2001. Can. Manuscr. Rep. Fish. Aquat. Sci. 2756: iii + 25 p.

A survey of red sea urchin populations was conducted in Fitz Hugh Sound (Pacific Fisheries Management sub-areas 8-3, 8-4, and 8-16) during August, 2001. A total of 60 transects were surveyed by SCUBA divers, and 1157 red sea urchins were measured. The total mean density of red sea urchins of all sizes was 1.49/m^2, and for legal-sized red sea urchins (≥90 mm TD) the density was 0.72/m^2. There was a significantly higher estimated density of red urchins ≤50 mm test diameter, TD found inside (4 transects) compared to outside (56 transects) previously fished commercial bed areas. Overall, 30.8% of all red urchins measured were ≤50 mm TD whereas 48.7% were of legal size for the commercial fishery.

RÉSUMÉ

Atkins, M., Tzotzos, D., Campbell, A., and Hajas, W.C. 2006. Survey of red sea urchin populations in Fitz Hugh Sound, British Columbia, 2001. Can. Manuscr. Rep. Fish. Aquat. Sci. 2756: iii + 25 p.

Un relevé des populations d'oursins rouges a été réalisé en août 2001 dans le détroit de Fitz Hugh (sous-secteurs 8-3, 8-4 et 8-16 de gestion des pêches du Pacifique). Au total, 60 transects ont été couverts par des plongeurs autonomes, qui ont mesuré 1157 oursins rouges. La densité moyenne totale des oursins rouges de toutes tailles était de 1,49/m^2 et, pour les oursins de taille réglementaire (≥90 mm de diamètre du test, DT), la densité était de 0,72/m^2. La densité estimée était nettement plus élevée chez les oursins rouges de ≤50 mm DT observés à l'intérieur (4 transects) qu'à l'extérieur (56 transects) de gisements auparavant exploités par la pêche commerciale. Dans l'ensemble, 30,8 % de tous les oursins rouges mesurés présentaient ≤50 mm DT, tandis que 48,7 % avaient la taille réglementaire pour la pêche commerciale.

INTRODUCTION

Red sea urchin (*Strongylocentrotus franciscanus*) distribution along the Pacific Coast of North America ranges from the southern tip of Baja California to Alaska (Kato and Schroeter 1985). Red sea urchins are found throughout shallow rocky subtidal habitats of British Columbia (Bernard 1977; Campbell and Harbo 1991). Red Sea urchins are commercially harvested for their gonads (roe), which are sold mainly in Japan. Coastal First Nations communities harvest sea urchins as part of their traditional food, social and ceremonial fisheries. The commercial red sea urchin fishery began in British Columbia (BC) in the early 1970's and the total landed value for the 2000-2001 season was $8.4 million (Campbell et al. 2001), making the red sea urchin fishery one of the most valuable shellfish fisheries in BC.

The commercial red sea urchin fishery history and management were described in Campbell and Harbo (1991), and Campbell et al. (1999a). Currently, several approaches are used in the management of the red sea urchin fishery, including: a minimum commercial harvest size of 90 mm test diameter (TD); area licensing; individual vessel quotas; area quotas; and limited licence entry. Quota calculations are based on estimates of urchin density from field surveys, and estimates of urchin bed areas. Density estimates are therefore essential to the assessment and management of the sea urchin fishery.

Early red sea urchin population surveys were conducted during the 1970's and 1980's by Breen et al. (1976, 1978), Adkins et al. (1981) and Sloan et al. (1987). Since 1993, red sea urchin population surveys have been conducted as a joint effort between the Pacific Urchin Harvesters Association (PUHA), First Nations, and Fisheries and Oceans Canada (DFO) (Jamieson et al. 1998a-d; Bureau et al. 2000a-d; Tzotzos et al. 2003a-d, 2006; Atkins et al. 2006a-g).

Fishery managers requested that red sea urchin surveys be conducted to update density and biomass estimates to help determine quotas. The Fitz Hugh Sound area [parts of Pacific Fishery Management (PFM) sub-areas 8-3, 8-4, and 8-16] (Figure 1), was selected for survey through discussion between PUHA and DFO. The objective of this paper was to present detailed survey results and to estimate current red sea urchin density and biomass for PFM sub-areas 8-3, 8-4, and 8-16.

METHODS

SURVEY AREA AND TRANSECT LAYOUT

Survey efforts were concentrated in PFM sub-areas 8-3, 8-4, and 8-16. Transect locations were selected and plotted on a marine chart prior to the survey to avoid bias in the field.

Transects were systematically placed along the shoreline with a random starting point. The ArcView GIS system was used to measure the shoreline length (SL) of the survey area, including islands. The position of the first transect was determined randomly, and subsequent transects were then spaced evenly along the shoreline. Areas of unsuitable red sea urchin habitat (eg. sand and mud substrates) were excluded from the survey area. Since variation in urchin density was unlikely to match the spacing of the transects, the systematic sample was treated as a random sample of transects (Jamieson and Schwarz 1998).

Survey Logistics

The survey was conducted from August 15-21 2001, on the "King Clam", a commercial red sea urchin fishing vessel. A crew consisting of three divers, one of which was a biologist and the others commercial urchin harvesters, and a boat tender was used for the survey.

Dive Survey Methods

In the field, locations of transects were determined from geographical references on the shoreline, and GPS. Exposure to wave action/current was recorded, for each transect, as one of nine codes: 0 = extreme shelter, 1 = minimal sea movement, 2 = well sheltered, 3 = occasional current, 4 = moderate exposure, 5 = strong tidal flow, 6 = high tide surge only, 7 = ground swell normal, 8 = high exposure. Leadline transects were laid perpendicular to shore from the boat, with a float attached to the deep end of each transect. Transects were laid out from shallow water to a depth of 15m (not corrected for tide), so transect length was dependent on the slope of the substrate and tide height. A two-diver team surveyed each transect from deep to shallow, one diver measured urchins while the other recorded data. A one meter squared (1 m^2) quadrat was placed on the bottom beside the transect and the test diameter (TD) of each red urchin present was measured, with callipers, to the nearest millimeter. If urchins could not be measured because they were inaccessible or broken/lost they were still counted, therefore the count of urchins in a quadrat may be higher than the number measured. The depth, substrate type, types of algae (and percent cover), shell length of abalone (*Haliotis kamtschatkana*), and TD of green (*S. droebachiensis*) and purple (*S. purpuratus*) sea urchins present in each quadrat were also recorded. The quadrat was then moved 2 m forward along the transect and the process was repeated, so that every second meter of the transect was surveyed. In cases where no urchins were found at the deep end of transects, observations of depth, substrate and algae were recorded only every 20 m to minimize dive time. In such cases, skipped quadrats were assigned zero values for urchin counts before the data were analysed. Once urchins were encountered, sampling was conducted every 2 m until the intertidal zone or the surface was reached.

DATA ANALYSIS

Habitat

Depth Categories

Gauge depths recorded by divers were corrected to depth below Chart Datum by subtracting tide height from the observed depths. Tide heights from the closest tide station were used to correct depths. The depth (m) for each quadrat was assigned to one of seven depth ranges: 1= <0.0m; 2= 0.0 - <2.5m; 3= 2.5 - <5.0m; 4= 5.0 - <7.5m; 5= 7.5 - <10.0m; 6= 10.0 -<12.5m; and 7= ≥12.5m.

Substrate

The divers recorded the dominant substrates (up to three) within each quadrat using one of nine generic codes: 1=smooth bedrock; 2=bedrock with crevices; 3=boulders, >30cm; 4=cobble, between 7.5cm and 30cm; 5=gravel, between 2cm and 7.5cm; 6=pea gravel, between 0.25-2cm; 7=sand; 8=shell; and 9=mud. For the analysis, the nine substrate codes were grouped into three main dominant categories: 1=rock (codes 1-5); 2=sand/shell (codes 6-8); and 3=mud (code 9). Each quadrat was assigned a dominant substrate code in order to determine the average percent of each dominant substrate.

Algae

Algal species were assigned to one of four categories based on growth characteristics: canopy (taller than 2m), understorey (30cm to 2m), turf (<30cm), and encrusting. The percent cover of algae in each category, for each quadrat, was calculated as the sum of the individual species' percent cover. Mean percent cover, by growth category, for each depth category was then calculated by averaging the quadrat percent covers over the depth category.

Estimation of Density and Biomass

Density and biomass estimates were calculated from transects that were located inside commercially harvested red sea urchin beds, for transects located outside of the harvested beds, and for all transects combined. Commercially harvested beds were defined as areas where commercial harvesting occurred between 1997 and 2000; therefore, areas defined as outside beds may have had fishing events prior to 1997 and/or after 2000. The process involved in defining the commercially harvested urchin beds was described by Campbell et al. (2001).

Density and biomass were estimated for red urchins in three size groups: a) all sizes, b) small urchins <50 mm TD, and c) urchins of legal size for the commercial fishery (≥90 mm TD). Estimates of mean density and biomass were calculated using the equations below.

Density estimates (d_{ts}) in number of red sea urchins per meter squared for each transect (t) and size group (s) were calculated as:

$$d_{ts} = \frac{N_{ct}}{a_t} * \frac{N_{mts}}{N_{mt}} \quad (1)$$

where N_{ct} is the total number of red urchins counted on transect t, N_{mts} is the number of red urchins measured in size group s on transect t, N_{mt} is the total number of red urchins measured on transect t, and a_t is the surface area of all quadrats surveyed on the transect t. Here a_t is equal to the number of all quadrats surveyed on the transect since each quadrat had a surface area of 1 m^2.

Overall mean density ($\bar{d}_s$) for a PFM sub-area, for urchins of size group s, was estimated as a weighted mean of transect densities:

$$\bar{d}_s = \frac{\sum_t (d_{ts} * L_t)}{\sum_t L_t} \quad (2)$$

where L_t is the length of transect t (Campbell et al. 1999b).

The standard error (s_d) of estimated mean density was calculated as:

$$s_d = \sqrt{1 - \frac{n}{T}} * \sqrt{\frac{\sum_t (d_{ts} * L_t - \bar{d}_s * L_t)^2}{n * (n-1) * \bar{L}^2}} \quad (3)$$

where n is the number of transects surveyed, T is the total possible number of transects that can be sampled in a surveyed PFM sub-area and mean transect length ($\bar{L}$) was calculated as:

$$\bar{L} = \frac{\sum_t L_t}{n} \quad \text{(Campbell et al. 1999b)} \quad (4)$$

The expression $\sqrt{(1-(n/T))}$ was approximately equal to 1 since n was much smaller than T.

To calculate biomass, the weight of each red urchin measured was calculated using the relationship between urchin weight (W) in grams and test diameter (TD) in millimetres (Campbell et al. 1999b, 2000).

$$W = 0.0012659 * TD^{2.7068} \quad n = 167,\ r^2 = 0.960 \quad (5)$$

Biomass density (b_{ts} in grams per meter squared) of urchins of size group s, on a transect t, was estimated using a simplified form of the formula used in previous papers (Campbell et al. 2000). The formula was modified by Campbell et al. (1999b) to simplify computations:

$$b_{ts} = \frac{N_{ct}}{N_{mt}} * \frac{\sum W_{ts}}{a_t} \quad (6)$$

where N_{ct} is the total number of red urchins counted on transect t, N_{mt} is the total number of red urchins measured on transect t, ΣW_{ts} is the sum of the weights of red urchins measured in size group s on transect t and a_t is the surface area of quadrats surveyed on the transect t.

Overall estimated mean biomass ($\bar{b}_s$) per surface area (grams per meter squared) was calculated as a weighted mean of transect biomass:

$$\bar{b}_s = \frac{\sum_t (b_{ts} * L_t)}{\sum_t L_t} \quad \text{(Campbell et al. 1999b)} \qquad (7)$$

The standard error of estimated mean biomass was calculated using the same formula used for standard errors of density, but d_{ts} and $\bar{d}_s$ were substituted for b_{ts} and $\bar{b}_s$, respectively. The biomass estimate, for each PFM sub-area surveyed, was converted into quota recommendations for management purposes by Campbell et al. (2001).

Observations from transects with a moderate exposure classification (transects: 1, 2, 6, 19, 25, 46-51, and 53) were not considered for analysis due to them being in areas of unsuitable red sea urchin habitat.

A Mann Whitney U Analysis (Systat 10) was used to compare the mean test diameter and densities of red urchins between inside and outside of commercial beds overall and for each PFM sub-area.

Density and biomass estimates were also generated by depth.

Recruitment

Estimates of recruitment (R_T) of red sea urchin populations in BC have generally been expressed as a percentage of the total number of red sea urchins measured that were ≤50 mm TD (Adkins et al. 1981; Breen et al. 1976, 1978; Jamieson et al. 1998b, 1998c, 1998d; Sloan et al. 1987). For comparison purposes, the same method was used here. Recruitment was also calculated as a percentage of the total number of sub-legal red sea urchins (<90 mm TD) that were ≤50 mm TD (R_S). This method may provide a less biased measure of recruitment in areas where a commercial fishery has taken place, since the numbers of sea urchins ≥90 mm TD may be reduced due to the harvest (Tegner and Dayton 1981).

RESULTS

SURVEY LOGISTICS

In total, 60 transects were surveyed during five dive days (Table 1, Figure 1), 48 of which were considered for analysis. A total of 1157 red sea urchins were counted and measured in 776 quadrats on the 48 transects. The total transect length surveyed was 1512 m, for an average length of 32 m. Four transects were located in the commercial red sea urchin beds recorded from 1997 to 2000.

SUBSTRATE AND HABITAT

All transects surveyed had a moderate or high exposure (Table 1), although only those with high exposure were considered in the analyses. Of the total (1031) quadrats sampled, 54% had rock, 32% had sand/shell, and 14% had mud as the primary substrate. Of the 1157 red sea urchins counted, 90% were observed between 0.0 m and 7.5 m depth.

Overall, canopy, understorey, and turf algae were found to increase in abundance with decreased depth; encrusting algae was consistently found at all depths surveyed. In PFM sub-area 8-3, canopy, understorey and turf algae were absent below 2.5 m depth (Table 2).

SIZE FREQUENCY DISTRIBUTIONS

The mean size of all red sea urchins measured was 74.7 mm TD (Table 3, Figure 2). The smallest and largest red urchins measured were 8 mm and 160 mm TD, respectively. By PFM sub-area, 8-3, 8-4 and 8-16 had a mean size of 79.3 mm TD, 80.9 mm TD and 66.3 mm TD, respectively. Overall, and by PFM sub-area where both bed types occurred, the mean size of urchins on commercial beds was significantly larger than outside bed areas.

The overall percentage of legal-sized red sea urchins (≥90 mm TD) was 48.7%, whereas the overall percentage of red urchins ≤50 mm TD (R_T) was 30.8%. Of the sublegal urchins, the percentage that was ≤50 mm TD (R_S) was 59.9%. By PFM sub-area, the proportion of legal-sized red sea urchins in sub-areas 8-3, 8-4 and 8-16 was 55.7%, 53.8%, and 40.7%, the percentage of urchin's ≤50 mm TD (R_T) was 22.1%, 23.6%, and 41.5%, and the percentage of sublegal urchins ≤50 mm TD (R_s) was 50.0%, 51.2% and 70.0%, respectively (Table 3).

Thirty seven percent (36.7%) of the red sea urchins sampled inside commercial bed areas (n=221) were of legal size, as were 51.5% of the urchins sampled outside commercial bed areas (n=936) (Table 3).

DENSITY AND BIOMASS ESTIMATES

For all transects combined, the estimated mean density and biomass for red urchins of all sizes was 1.49/m^2 and 364.39 g/m^2, respectively, and 0.72/m^2 and 312.49 g/m^2 for legal-sized urchins (Table 4). Significant differences in density of red urchins between in and out of bed areas were observed for urchin's ≤50 mm TD (Table 5).

Overall (PFM sub-areas combined), for transects lying on red sea urchin beds, the estimated mean density of red urchins of all sizes was 3.16/m^2, and was 1.16/m^2 for legal-sized urchins. For transects lying outside of commercial bed areas, the estimated mean density was 1.32/m^2 for red urchins of all sizes, and 0.68/m^2 for legal-sized urchins. Inside bed areas, the estimated mean biomass of red sea urchins of all sizes was 576.72 g/m^2, and was 524.23 g/m^2 for legal-sized urchins; outside bed areas the estimated mean biomass was 343.40 g/m^2 and 291.56 g/m^2, respectively (Table 4).

By PFM sub-area, the estimated mean density for red urchins of all sizes in sub-areas 8-3, 8-4, and 8-16 was 2.66/m^2, 1.35/m^2; and 1.49/m^2, and the mean density of legal-sized urchins was 1.48/m^2, 0.72/m^2, and 0.61/m^2, respectively (Table 4). When comparing densities by PFM sub-area between inside and outside of commercial bed areas there were no statistical differences observed for red urchins in any size category (Table 5).

Mean density and biomass estimates by depth category for red sea urchins in all size categories were calculated, and the results are displayed in tables 6 and 7 for both inside and outside of commercial bed areas; however, no statistical testing was performed. The highest density and biomass estimates were found in the 10 – 12.5m depth category, although only eight transects were surveyed in this depth range.

DISCUSSION

There are a number of possible hypotheses to explain the significant difference in mean test diameter observed between inside and outside commercial bed areas such as heavy fishing in bed areas resulting in the removal of larger red sea urchins, low recruitment outside of bed areas causing a higher mean size with few small red urchins, or simply an artefact of low sample size inside bed areas.

The percent of legal-sized red urchins was lower inside bed areas compared to outside harvested beds; this coupled with recruitment (R_T) inside bed areas more than double that of outside beds, suggests that commercial fishing may be removing adults from the population, although with such a low number of transects sampled inside commercial beds (4 transects) it is difficult to make any comparisons. Figure 2 shows evidence of a recruitment pulse for all areas both inside and outside of commercial beds, suggesting that recruitment is not a concern at this time in Fitz Hugh Sound. Recruitment is defined here as the percent of the total red sea urchin population that was ≤50 mm TD (R_T). Numerous factors could influence recruitment in any given area

including physical and oceanographic influences, predation on larvae and juveniles, and interactions between juveniles and adults (Kalvass 1992; Sloan et al. 1987).

When compared with other recent surveys the overall mean density of red sea urchins (all sizes) observed in commercially harvested bed areas in Fitz Hugh Sound (3.16/m^2) was higher than two recent surveys in Queen Charlotte Strait: the first in 2000 in the Deserters Group (2.12/m^2) (Tzotzos et al. 2003c), and the other in 2004 (2.83/m^2) (Atkins et al. 2006g); and was similar to a recent survey at Campania Island (2004) where densities of red sea urchins in known commercial beds was 3.20/m^2 (Atkins et al. 2006c).

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Table 1. Summary of transects surveyed during the August 15 - 21, 2001 red sea urchin (RSU) population survey in Fitz Hugh Sound. Density in number per meter squared and biomass in grams per meter squared. PFM = Pacific Fishery Management. Depths have been corrected to chart datum. Exposure values: 4=moderate exposure; 8=high exposure. Check marks (✓) indicate transect lying within a known commercial RSU bed.

	PFM			Depth (m)			Time		Total Time	Transect	Number	Number RSU	RSU	RSU	In
Transect	Sub-Area	Latitude	Longitude	Minimum	Maximum	Exposure	Start	End	(minutes)	Length(m)	Quadrats	Counted	Density	Biomass	Bed
1	8-4	52 3.967	127 51.16	-0.46	9.36	4	11:16	11:20	4	23	12	0	0.00		
2	8-4	52 2.909	127 51.545	0.09	8.75	4	10:55	11:03	8	41	21	0	0.00		
3	8-4	52 1.933	127 53.662	-0.40	9.75	8	10:31	10:36	5	21	11	0	0.00		
4	8-4	51 59.527	127 53.936	0.76	13.01	8	9:36	10:01	25	49	25	45	1.80	659.34	
5	8-4	51 58.986	127 53.772	1.01	11.28	8	9:07	9:23	16	47	24	7	0.29	152.81	
6	8-4	51 58.12	127 52.998	0.15	9.51	4	15:50	16:00	10	93	47	0	0.00		
7	8-4	51 57.529	127 54.401	-0.70	9.27	8	15:28	15:37	9	23	12	1	0.08	46.84	
8	8-4	51 57.375	127 53.322	-1.52	8.99	8	15:02	15:18	16	35	18	0	0.00		
9	8-4	51 55.89	127 54.198	-0.37	8.53	8	14:05	14:40	35	79	40	98	2.45	341.18	
10	8-4	51 52.754	127 53.021	-1.10	8.35	8	12:58	13:13	15	17	9	2	0.22	59.79	
11	8-4	51 52.321	127 52.27	-2.01	8.38	8	12:40	12:49	9	23	12	7	0.58	114.77	
12	8-4	51 51.859	127 51.758	-2.26	8.14	8	12:18	12:30	12	23	12	1	0.08	0.16	
13	8-4	51 51.337	127 52.997	-1.77	8.69	8	11:45	11:55	10	13	7	29	4.14	1274.65	
14	8-4	51 50.626	127 52.363	-1.89	8.38	8	11:11	11:32	21	19	10	15	1.50	72.09	
15	8-4	51 49.909	127 53.137	-1.19	9.30	8	10:47	10:56	9	15	8	1	0.13	18.15	
16	8-3	51 47.09	127 53.136	-0.46	9.72	8	10:14	10:23	9	13	7	19	2.71	784.05	
17	8-3	51 45.725	127 52.467	0.21	2.50	8	9:46	9:55	9	51	26	11	0.42	114.03	
18	8-16	51 42.917	127 53.498	0.00	9.63	8	15:13	15:29	16	25	13	31	2.38	761.42	
19	8-16	51 42.661	127 52.195	-0.12	7.77	4	15:43	15:50	7	91	46	0	0.00		
20	8-16	51 41.559	127 53.125	-0.85	9.36	8	14:43	14:59	16	95	48	32	0.67	232.72	
21	8-16	51 40.026	127 52.124	-1.25	8.75	8	14:05	14:13	8	53	27	2	0.07	19.18	✓
22	8-16	51 38.628	127 50.774	-0.24	8.53	8	13:32	13:41	9	61	31	0	0.00		
23	8-16	51 38.612	127 50.69	-0.37	8.72	8	13:09	13:21	12	61	31	1	0.03	0.10	
24	8-16	51 38.461	127 50.7	1.07	8.66	8	12:47	12:59	12	41	21	13	0.62	211.39	
25	8-16	51 39.864	127 49.271	-1.74	8.32	4	12:10	12:13	3	31	16	0	0.00		
26	8-16	51 37.734	127 49.25	-1.37	8.75	8	11:27	11:36	9	27	14	0	0.00		
27	8-16	51 37.003	127 47.784	-1.16	8.99	8	10:13	10:22	9	19	10	1	0.10	60.02	
28	8-16	51 37.411	127 49.839	-1.58	8.81	8	11:13	11:18	5	19	10	7	0.70	190.11	
29	8-16	51 36.965	127 50.504	-0.55	9.02	8	10:42	10:58	16	35	18	7	0.39	35.50	

Continued next page

Table 1. continued

Transect	PFM Sub-Area	Latitude	Longitude	Depth (m) Minimum	Depth (m) Maximum	Exposure	Time Start	Time End	Total Time (minutes)	Transect Length(m)	Number Quadrats	Number RSU Counted	RSU Density	RSU Biomass	In Bed
30	8-16	51 36.58	127 49.684	-0.94	9.27	8	9:45	10:01	16	39	20	2	0.10	61.55	
31	8-16	51 36.558	127 54.864	-0.67	9.30	8	12:29	13:00	31	65	33	127	3.85	552.10	
32	8-16	51 38.761	127 57.296	-0.40	9.91	8	11:53	12:06	13	21	11	44	4.00	714.37	✓
33	8-16	51 40.507	127 58.121	0.43	10.76	8	11:02	11:36	34	41	21	172	8.19	1521.76	✓
34	8-16	51 42.324	127 59.083	1.22	10.82	8	10:39	10:48	9	13	7	33	4.71	1589.47	
35	8-3	51 44.022	127 59.74	0.64	11.03	8	9:56	10:25	29	31	16	101	6.31	1428.25	
36	8-4	51 45.903	128 0.453	-1.19	8.78	8	12:28	12:46	18	49	25	48	1.92	567.21	
37	8-4	51 46.632	128 0.01	-0.82	9.11	8	12:05	12:18	13	15	8	50	6.25	1631.56	
38	8-4	51 47.779	128 0.668	-1.22	8.99	8	11:35	11:45	10	43	22	0	0.00		
39	8-4	51 47.634	128 1.431	-1.19	9.85	8	11:20	11:25	5	25	13	2	0.15	75.84	
40	8-4	51 48.164	128 3.24	1.86	12.01	8	9:00	9:17	17	13	7	1	0.14	130.55	
41	8-4	51 45.894	128 3.454	0.91	11.92	8	9:20	9:26	6	17	9	0	0.00		
42	8-4	51 44.948	128 3.039	-1.52	8.14	8	15:23	15:36	13	19	9	56	6.22	1585.90	
43	8-4	51 44.588	128 6.508	-0.18	8.44	8	15:58	16:16	18	27	14	44	3.14	861.56	
44	8-4	51 44.84	128 6.137	-1.43	8.78	8	16:25	16:37	12	15	8	34	4.25	853.43	
45	8-4	51 45.378	128 4.649	-0.73	9.14	8	16:53	17:05	12	21	11	3	0.27	1.15	✓
46	8-4	51 45.983	128 5.395	1.62	6.49	4	8:20	8:25	5	31	16	0	0.00		
47	8-4	51 45.972	128 4.951	1.95	12.01	4	8:32	8:38	6	17	9	0	0.00		
48	8-4	51 47.229	128 4.548	1.34	12.01	4	8:49	8:55	6	13	7	2	0.29	80.03	
49	8-4	51 48.794	128 3.108	-0.88	10.15	4	11:02	11:07	5	17	9	0	0.00		
50	8-4	51 49.446	128 2.005	0.30	7.44	4	10:40	10:50	10	71	36	0	0.00		
51	8-4	51 50.726	128 0.553	-0.03	11.00	4	10:09	10:14	5	51	26	0	0.00		
52	8-4	51 52.255	128 0.611	0.30	11.40	8	9:39	9:50	11	19	10	22	2.20	975.39	
53	8-4	51 53.82	128 0.819	-2.01	8.60	4	15:18	15:26	8	19	10	0	0.00		
54	8-4	51 53.929	128 0.036	-0.61	8.38	8	14:57	15:12	15	33	17	15	0.88	419.17	
55	8-4	51 55.226	127 58.517	-1.77	8.23	8	14:30	14:43	13	21	11	31	2.82	1106.69	
56	8-4	51 56.055	127 57.938	-2.80	8.11	8	13:56	14:20	24	43	22	20	0.91	358.94	
57	8-4	51 57.824	127 57.402	-1.34	8.11	8	13:27	13:34	7	21	8	1	0.13	51.79	
58	8-4	52 1.04	127 57.215	-1.49	8.29	8	12:52	12:57	5	21	11	0	0.00		
59	8-4	52 2.014	127 57.28	-0.79	8.41	8	12:33	12:42	9	13	7	0	0.00		
60	8-4	51 53.258	127 57.102	-1.19	8.78	8	12:00	12:18	18	23	12	21	1.75	604.38	

Table 2. Mean number of red sea urchins (RSU), mean substrate category, and percent cover by algae grouping for each depth range surveyed during the 2001 survey conducted in Fitz Hugh Sound. Depth ranges have been corrected to chart datum. Substrate categories: 1 = rock; 2 = sand/shell; 3 = mud. Canopy = tall, shading, surface-reaching algae. Understorey = 30cm to 2m in height. Turf = 5cm to 30cm in height. Encrusting = species forming a thin, crustose layer on rocks.

Depth	Number of RSU		Number	Mean Substrate	Mean Percent Cover by Algae			
Range (m)	Total	Mean per Quadrat	Of Quadrats	Category	Canopy	Understorey	Turf	Encrusting
PFM sub-area 8-3								
<0.0 m	0	0.00	1	1.00	0.00	90.00	0.00	90.00
0.0 - <2.5 m	63	2.33	27	1.85	6.67	20.00	11.11	41.11
2.5 - <5.0 m	31	5.17	6	1.00	0.00	0.00	0.00	90.00
5.0 - <7.5 m	21	5.25	4	1.00	0.00	0.00	0.00	90.00
7.5 - <10.0 m	16	2.67	6	1.17	0.00	0.00	0.00	76.67
10.0 - <12.5 m	0	0.00	2	1.00	0.00	0.00	0.00	90.00
PFM sub-area 8-4								
<0.0 m	0	0.00	39	1.00	11.94	24.47	35.14	78.33
0.0 - <2.5 m	127	1.48	86	1.20	20.53	19.62	14.80	70.61
2.5 - <5.0 m	170	1.70	100	1.81	7.99	14.11	4.11	41.39
5.0 - <7.5 m	201	2.03	99	1.79	1.88	10.03	5.61	39.06
7.5 - <10.0 m	42	0.58	73	1.88	0.22	3.16	2.33	31.11
10.0 - <12.5 m	7	0.70	10	1.60	0.00	1.43	0.00	65.71
≥12.5 m	1	1.00	1	2.00	0.00	0.00	0.00	0.00
PFM sub-area 8-16								
<0.0 m	2	0.08	25	1.24	12.94	27.94	15.88	65.29
0.0 - <2.5 m	166	2.00	83	1.36	16.43	26.24	9.52	74.29
2.5 - <5.0 m	129	1.55	83	1.76	2.40	13.00	1.90	41.90
5.0 - <7.5 m	130	1.67	78	1.82	2.50	2.75	1.25	51.63
7.5 - <10.0 m	36	0.83	43	1.74	0.00	1.04	7.50	50.00
10.0 - <12.5 m	9	4.50	2	1.00	0.00	0.00	0.00	90.00
PFM sub-areas 8-3, 8-4, and 8-16 combined								
<0.0 m	2	0.03	65	1.09	12.04	26.78	28.43	74.44
0.0 - <2.5 m	356	1.82	196	1.36	17.99	22.03	12.62	69.66
2.5 - <5.0 m	330	1.74	189	1.76	5.43	13.02	3.05	43.87
5.0 - <7.5 m	352	1.94	181	1.78	2.04	6.96	3.79	45.60
7.5 - <10.0 m	94	0.77	122	1.80	0.13	2.23	3.80	40.80
10.0 - <12.5 m	16	1.14	14	1.43	0.00	1.00	0.00	73.00
≥12.5 m	1	1.00	1	2.00	0.00	0.00	0.00	0.00

Table 3. Number of red sea urchins measured and percentage of red urchin's ≤50 mm and ≥90 mm TD for each Pacific Fishery Management (PFM) sub-area surveyed during the 2001 population survey in Fitz Hugh Sound. R_T = percent of all red urchins that were ≤50 mm TD. R_S = percent of sublegal urchins that were ≤50 mm TD.

PFM	Transects	Test Diameter (mm)			Numbers Measured			% Total Measured		% Sublegal
Sub-area	Used	Mean	Minimum	Maximum	Total	≤50 mm TD	≥90 mm TD	≤50 mm	≥90 mm (R_T)	≤50 mm (R_S)
8-3	Within Beds					none surveyed				
	Outside Beds	79.3	8	125	131	29	73	22.1	55.7	50.0
	All	79.3	8	125	131	29	73	22.1	55.7	50.0
8-4	Within Beds	20.0	19	21	3	3	0	100.0	0.0	100.0
	Outside Beds	81.2	8	157	551	128	298	23.2	54.1	50.6
	All	80.9	8	157	554	131	298	23.6	53.8	51.2
8-16	Within Beds	58.4	9	137	218	116	81	53.2	37.2	84.7
	Outside Beds	73.1	8	160	254	80	111	31.5	43.7	55.9
	All	66.3	8	160	472	196	192	41.5	40.7	70.0
Survey	Within Beds	57.9	9	137	221	119	81	53.8	36.7	85.0
Total	Outside Beds	78.7	8	160	936	237	482	25.3	51.5	52.2
	All	74.7	8	160	1157	356	563	30.8	48.7	59.9

Table 4. Mean density and biomass estimates of red sea urchins by size (test diameter, TD), within and outside of commercial beds, by Pacific Fishery Management sub-area, for the 2001 survey in Fitz Hugh Sound. Estimates are for transects within red sea urchin beds recorded between 1997 and 2000, for transects outside the beds, and for all transects combined. Values in brackets are ± S.E.

PFM Sub-areas	Transects Surveyed	Number Of Transects	Sum of Transect Lengths (m)	Mean Density (/m^2) by TD			Mean Biomass (g/m^2) by TD		
				≤50 mm	≥90 mm	All Sizes	≤50 mm	≥90 mm	All Sizes
8-3	Within Beds			none surveyed					
	Outside Beds	3	95	0.59	1.48	2.66	5.90	530.29	634.57
	All	3	95	0.59	1.48	2.66	5.90	530.29	634.57
8-4	Within Beds	1	21	0.27	0.00	0.27	1.15	0.00	1.15
	Outside Beds	29	781	0.32 (0.16)	0.74 (0.15)	1.37 (0.28)	2.52 (1.05)	328.51 (59.92)	380.89 (71.81)
	All	30	802	0.32 (0.16)	0.72 (0.15)	1.35 (0.27)	2.48 (1.02)	319.91 (58.93)	370.95 (70.49)
8-16	Within Beds	3	115	1.96	1.37	3.68	10.26	619.96	681.83
	Outside Beds	12	500	0.31 (0.22)	0.43 (0.15)	0.99 (0.46)	1.67 (0.92)	188.48 (61.78)	229.52 (79.82)
	All	15	615	0.62 (0.33)	0.61 (0.22)	1.49 (0.63)	3.28 (1.74)	269.16 (98.10)	314.10 (113.03)
Survey Total	Within Beds	4	136	1.70	1.16	3.16	8.86	524.23	576.72
	Outside Beds	44	1376	0.34 (0.12)	0.68 (0.12)	1.32 (0.26)	2.44 (0.76)	291.56 (48.07)	343.40 (58.21)
	All	48	1512	0.46 (0.16)	0.72 (0.13)	1.49 (0.31)	3.02 (0.93)	312.49 (54.32)	364.39 (63.77)

Table 5. Kruskal-Wallace test results for comparing mean densities of red sea urchins by size groups between inside and outside commercial bed areas by PFM sub-area for the 2001 survey in Fitz Hugh Sound.

PFM Sub-areas	P-values		
	≤50 mm	≥90 mm	All Sizes
8-3	n/a	n/a	n/a
8-4	0.294	0.219	0.862
8-16	0.053	0.310	0.247
Sub-areas combined	**0.025**	0.866	0.432

Table 6. Mean density estimates of red sea urchins by depth range for all urchins surveyed inside commercial beds, outside commercials beds, and total urchins surveyed, during the 2001 survey conducted in Fitz Hugh Sound. Values in brackets are ± S.E.

Depth Range (m)	Transect Count	Mean Density (/m^2) by test diameter								
		≤50 mm			≥90 mm			All Sizes		
		In	Out	Total	In	Out	Total	In	Out	Total
PFM sub-area 8-3										
<0.0 m	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.0– <2.5 m	3	0.00	1.49	1.49	0.00	3.24	3.24	0.00	5.91	5.91
2.5 – <5.0 m	2	0.00	0.87	0.87	0.00	3.04	3.04	0.00	5.45	5.45
5.0 – <7.5 m	2	0.00	1.18	1.18	0.00	3.18	3.18	0.00	5.76	5.76
7.5 – <10.0 m	2	0.00	0.59	0.59	0.00	1.50	1.50	0.00	2.73	2.73
10.0 – <12.5 m	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
≥12.5 m	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PFM sub-area 8-4										
<0.0 m	25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.0– <2.5 m	30	0.00	0.12 (0.08)	0.11 (0.07)	0.00	0.69 (0.24)	0.68 (0.23)	0.00	1.25 (0.45)	1.22 (0.44)
2.5 – <5.0 m	30	1.00	0.27 (0.10)	0.29 (0.10)	0.00	1.00 (0.25)	0.98 (0.25)	1.00	1.72 (0.45)	1.70 (0.43)
5.0 – <7.5 m	30	0.00	0.98 (0.74)	0.96 (0.72)	0.00	1.19 (0.32)	1.16 (0.32)	0.00	2.49 (0.97)	2.43 (0.95)
7.5 – <10.0 m	30	0.00	0.21 (0.10)	0.20 (0.10)	0.00	0.41 (0.09)	0.40 (0.09)	0.00	0.76 (0.17)	0.74 (0.17)
10.0 – <12.5 m	5	0.00	0.05 (0.06)	0.05 (0.06)	0.00	0.38 (0.38)	0.38 (0.38)	0.00	0.44 (0.44)	0.44 (0.44)
≥12.5 m	1	0.00	0.02	0.02	0.00	0.80	0.80	0.00	1.00	1.00
PFM sub-area 8-16										
<0.0 m	11	0.00	0.00	0.00	0.00	0.02 (0.02)	0.02 (0.02)	0.00	0.05 (0.05)	0.04 (0.04)
0.0– <2.5 m	15	2.35	0.65 (0.57)	0.97 (0.58)	1.61	0.71 (0.38)	0.88 (0.39)	4.40	1.87 (1.23)	2.34 (1.18)
2.5 – <5.0 m	15	1.63	0.36 (0.27)	0.60 (0.28)	1.20	0.38 (0.19)	0.53 (0.21)	3.08	1.04 (0.59)	1.42 (0.58)
5.0 – <7.5 m	15	2.65	0.31 (0.17)	0.75 (0.47)	1.80	0.53 (0.24)	0.77 (0.35)	4.96	1.02 (0.41)	1.75 (0.89)
7.5 – <10.0 m	15	1.49	0.07 (0.04)	0.34 (0.21)	1.06	0.13 (0.06)	0.30 (0.15)	2.81	0.24 (0.10)	0.72 (0.39)
10.0 – <12.5 m	2	2.67	0.24	2.09	1.80	2.67	2.01	5.00	4.00	4.76
≥12.5 m	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

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Table 6. continued.

Depth Range (m)	Transect Count	Mean Density (/m^2) by test diameter								
		≤50 mm			≥90 mm			All Sizes		
		In	Out	Total	In	Out	Total	In	Out	Total
All PFM sub-areas combined										
<0.0 m	37	0.00	0.00	0.00	0.00	0.01 (0.01)	0.01 (0.01)	0.00	0.02 (0.02)	0.02 (0.02)
0.0– <2.5 m	48	1.98	0.41 (0.23)	0.55 (0.26)	1.36	0.88 (0.28)	0.92 (0.27)	3.72	1.80 (0.62)	1.97 (0.62)
2.5 – <5.0 m	47	1.53	0.32 (0.12)	0.43 (0.13)	1.01	0.83 (0.18)	0.85 (0.17)	2.76	1.59 (0.36)	1.70 (0.35)
5.0 – <7.5 m	47	2.24	0.74 (0.45)	0.88 (0.44)	1.52	1.01 (0.22)	1.06 (0.23)	4.19	2.04 (0.62)	2.24 (0.65)
7.5 – <10.0 m	47	1.26	0.17 (0.06)	0.27 (0.10)	0.90	0.34 (0.07)	0.39 (0.08)	2.38	0.63 (0.13)	0.79 (0.19)
10.0 – <12.5 m	8	2.67	0.06 (0.05)	0.52 (0.45)	1.80	0.48 (0.35)	0.71 (0.39)	5.00	0.61 (0.45)	1.39 (0.88)
≥12.5 m	1	0.00	0.02	0.02	0.00	0.80	0.80	0.00	1.00	1.00

Table 7. Biomass estimates of red sea urchins by depth range for all urchins surveyed inside commercial beds, outside commercials beds, and total urchins surveyed, during the 2001 survey conducted in Fitz Hugh Sound. Values in brackets are ± S.E.

Depth Range (m)	Transect Count	Mean Biomass (g/m^2) by test diameter								
		≤50 mm			≥90 mm			All Sizes		
		In	Out	Total	In	Out	Total	In	Out	Total
PFM sub-area 8-3										
<0.0 m	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.0 – <2.5 m	3	0.00	15.54	15.54	0.00	1141.53	1141.53	0.00	1355.88	1355.88
2.5 – <5.0 m	2	0.00	9.35	9.35	0.00	1097.83	1097.83	0.00	1362.58	1362.58
5.0 – <7.5 m	2	0.00	12.66	12.66	0.00	1130.45	1130.45	0.00	1377.54	1377.54
7.5 – <10.0 m	2	0.00	6.33	6.33	0.00	532.72	532.72	0.00	646.10	646.10
10.0 – <12.5 m	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
≥12.5 m	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PFM sub-area 8-4										
<0.0 m	25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.0 – <2.5 m	30	0.00	2.40 (1.86)	2.33 (1.81)	0.00	283.18 (97.83)	275.76 (95.26)	0.00	356.09 (122.96)	346.76 (119.71)
2.5 – <5.0 m	30	4.22	3.53 (1.82)	3.55 (1.78)	0.00	433.99 (104.40)	422.63 (101.97)	4.22	509.77 (126.65)	496.54 (123.64)
5.0 – <7.5 m	30	0.00	3.52 (1.26)	3.43 (1.23)	0.00	544.98 (149.76)	530.71 (146.97)	0.00	601.39 (156.97)	585.64 (154.08)
7.5 – <10.0 m	30	0.00	1.61 (0.59)	1.57 (0.58)	0.00	196.27 (46.83)	191.13 (45.88)	0.00	220.64 (51.79)	214.86 (50.71)
10.0 – <12.5 m	5	0.00	1.32 (1.47)	1.32 (1.47)	0.00	213.93 (200.45)	213.93 (200.45)	0.00	215.25 (201.88)	215.25 (201.88)
≥12.5 m	1	0.00	0.84	0.84	0.00	328.43	328.43	0.00	366.30	366.30

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Table 7. continued.

Depth Range (m)	Transect Count	Mean Biomass (g/m^2) by test diameter								
		≤50 mm			≥90 mm			All Sizes		
		In	Out	Total	In	Out	Total	In	Out	Total
PFM sub-area 8-16										
<0.0 m	11	0.00	0.00	0.00	0.00	7.91 (8.60)	6.73 (7.19)	0.00	12.26 (13.32)	10.42 (11.14)
0.0– <2.5 m	15	12.70	3.35 (2.46)	5.10 (2.83)	736.32	291.72 (154.71)	374.86 (167.24)	813.23	377.51 (205.58)	458.98 (205.14)
2.5 – <5.0 m	15	7.47	1.65 (1.17)	2.74 (1.28)	529.82	154.93 (77.07)	225.03 (86.47)	573.68	204.66 (103.37)	273.66 (104.89)
5.0 – <7.5 m	15	14.87	1.74 (0.92)	4.20 (2.69)	830.28	257.36 (125.47)	364.49 (166.50)	920.23	286.22 (127.08)	404.77 (179.70)
7.5 – <10.0 m	15	7.41	0.40 (0.21)	1.71 (1.11)	471.29	66.38 (30.90)	142.09 (67.14)	516.34	72.09 (31.66)	155.16 (73.32)
10.0 – <12.5 m	2	15.22	4.28	12.59	836.94	1170.81	917.32	928.98	1348.64	1030.01
≥12.5 m	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
All PFM sub-areas combined										
<0.0 m	37	0.00	0.00	0.00	0.00	3.11 (3.17)	2.86 (2.90)	0.00	4.82 (4.91)	4.43 (4.50)
0.0 – <2.5 m	48	10.74	3.65 (1.70)	4.29 (1.75)	622.62	345.54 (103.77)	370.47 (103.85)	687.66	432.90 (129.35)	455.81 (126.80)
2.5 – <5.0 m	47	6.97	3.02 (1.18)	3.38 (1.13)	448.01	350.73 (75.65)	359.79 (71.82)	485.75	422.95 (92.25)	428.80 (86.67)
5.0 – <7.5 m	47	12.57	3.15 (0.89)	4.03 (1.33)	702.07	455.89 (103.75)	478.81 (107.98)	778.14	508.23 (109.13)	533.36 (115.24)
7.5 – <10.0 m	47	6.27	1.31 (0.41)	1.77 (0.58)	398.52	158.43 (34.07)	180.77 (39.20)	436.61	178.71 (37.88)	202.72 (43.46)
10.0 – <12.5 m	8	15.22	1.31 (1.14)	3.79 (2.63)	836.94	244.66 (173.42)	350.24 (184.30)	928.98	257.90 (181.85)	377.53 (199.07)
≥12.5 m	1	0.00	0.84	0.84	0.00	328.43	328.43	0.00	366.30	366.30

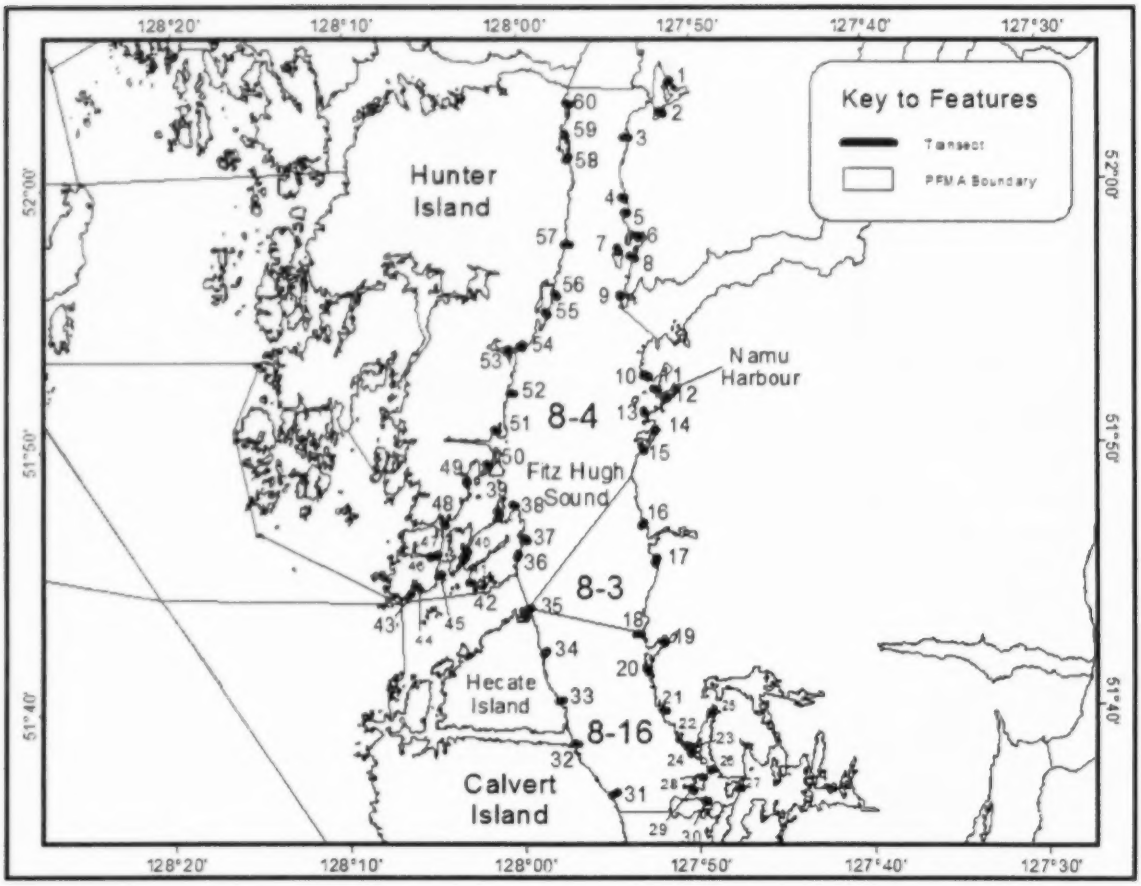

Figure 1. Map of survey area and transect locations for the red sea urchin population survey conducted in Fitz Hugh Sound, 2001. Hyphenated numbers indicate Pacific Fishery Management sub-areas and smaller numbers identify transect locations.

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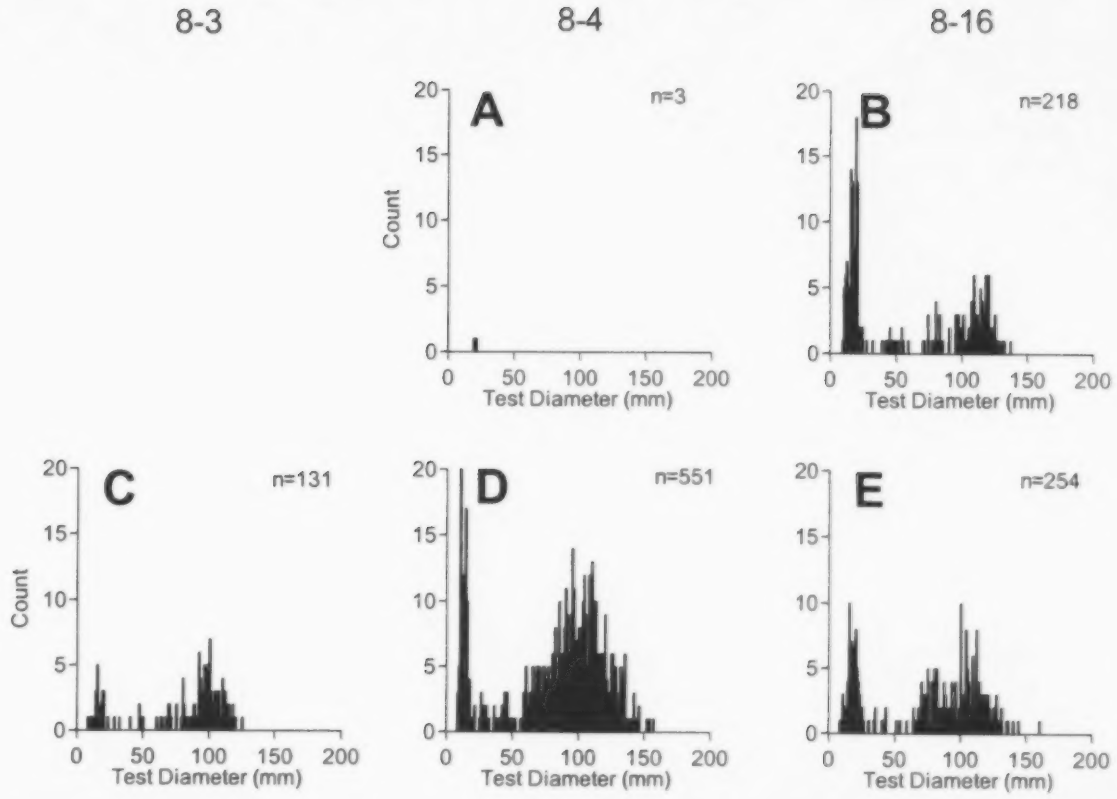

Figure 2. Size frequency distribution of red sea urchins measured along transects inside (A, B) and outside (C, D, E) of commercial bed areas during the 2001 survey in Fitz Hugh Sound. Pacific Management sub-areas are indicated above the figures. n= number of red sea urchins measured for test diameter.